45th International Conference on Environmental Systems

# Analysis of Process Gases and Trace Contaminants in Membrane-Aerated Bioreactor Gaseous Effluent Streams

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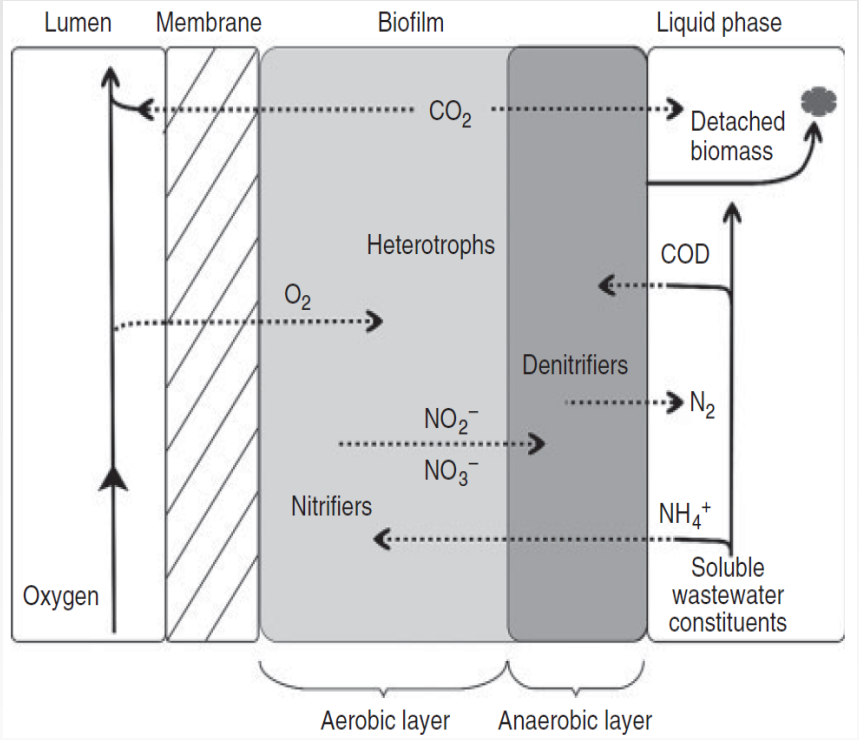
- Role of Bioreactors in Space Exploration
- Why do we care about gases in bioreactors?
- Sample Collection and Analysis Methodology
- Results
  - Effluent Gas Profiles
  - Quantification of Process Gases
  - Quantification of Trace Contaminants
- Implications for Environmental Controls

# Bioreactors and Space Exploration

- Alternative Water Processor
  - Designed as a possible replacement to current water treatment that utilized harsh chemicals and produces a very hazardous brine
  - Utilizes microbes as a pretreatment to wastewater to knock down TOC and mineralize urine-nitrogen
  - After this bioreactor pretreatment, a final polishing step using forward osmosis is utilized to make the water potable
  - Eliminates the need for caustic urine pretreatment chemicals

# Why Consider Effluent Gases?

- MABR Design
  - Feeds oxygen into system
  - Strips other gases out of system
    - These must be identified and quantified for closed environment venting
- Current data available:
  - Oxygen diffusion across membranes
  - $CO_2$ stripping in relation to gas flow rate
  - Little to no data on other gas species

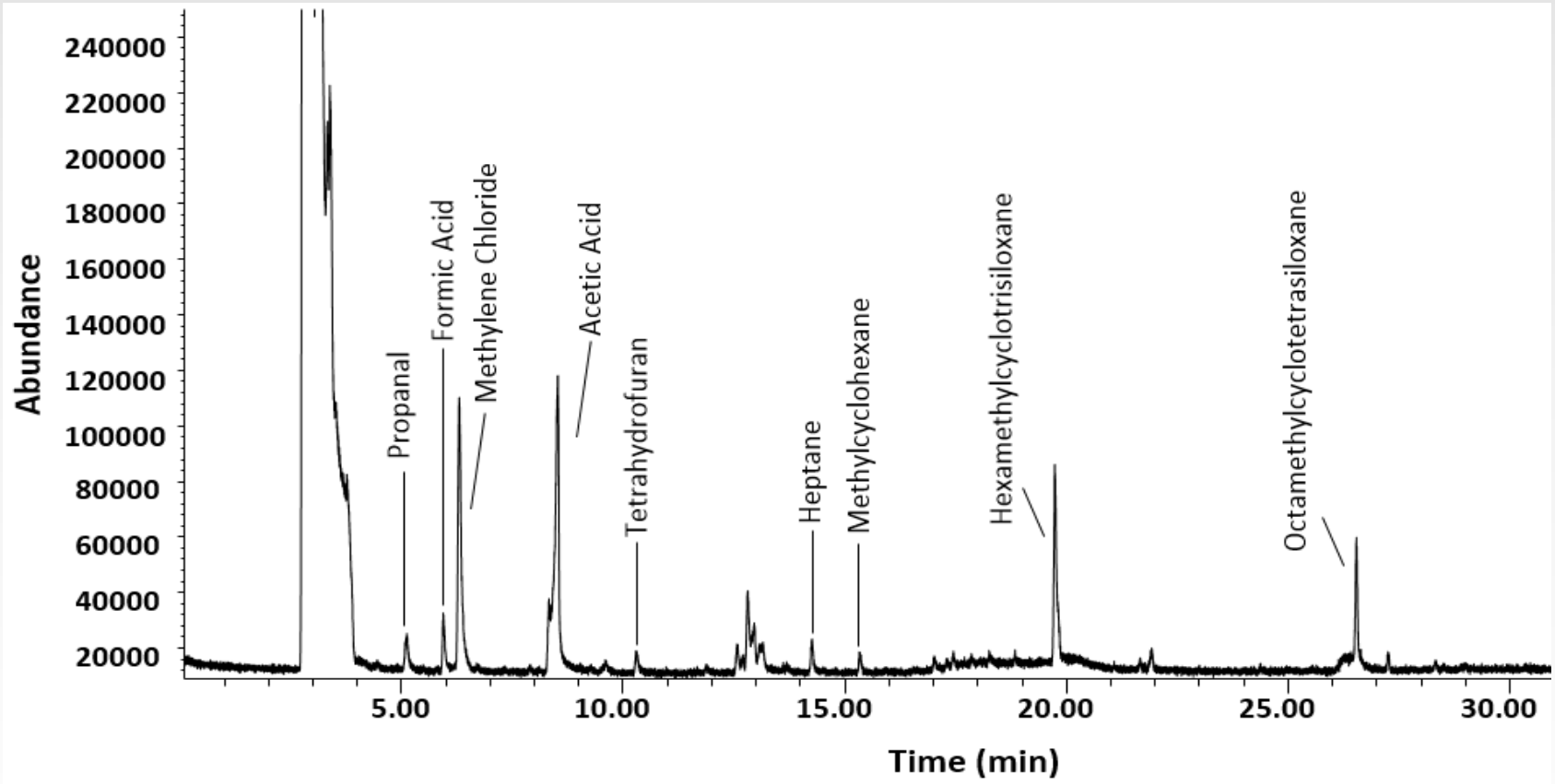



Transport fluxes of soluble constituents and microbial stratification within biofilms developed on membranes within nitrification-denitrification MABRs according to Syron and Casey[1].

# Analysis Methodology

- Identification of Effluent Gas Constituents
  - FT-IR Analysis
    - Powerful tool capable of identifying constituents in unknown gas mixtures, and in some cases quantifying constituents
    - Highly dependent on analysis software
  - SPME-GC-MS Analysis
    - Great for VOC identification
- Quantification of Constituents
  - Gas Chromatography
    - GC-MS, GC-TCD, GC-ECD, GC-FID

# SPME Analysis of KSC Systems for VOCs

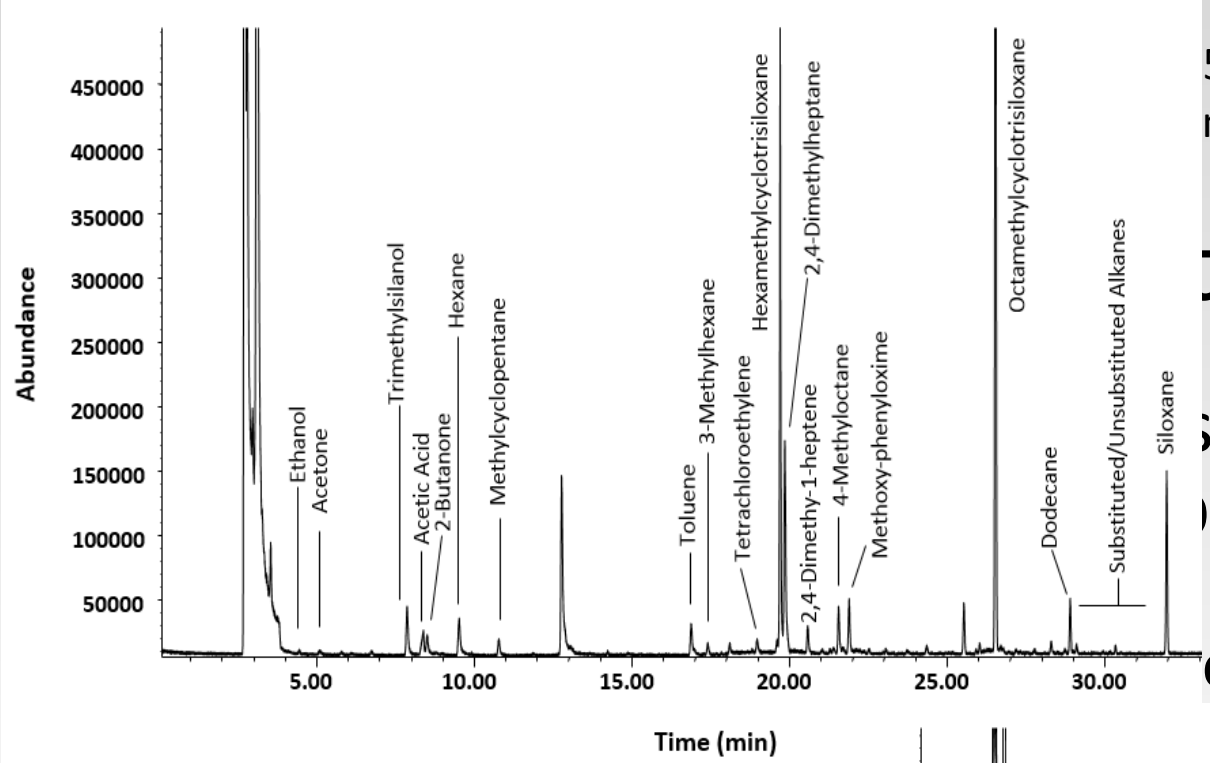


# tems for VOCs

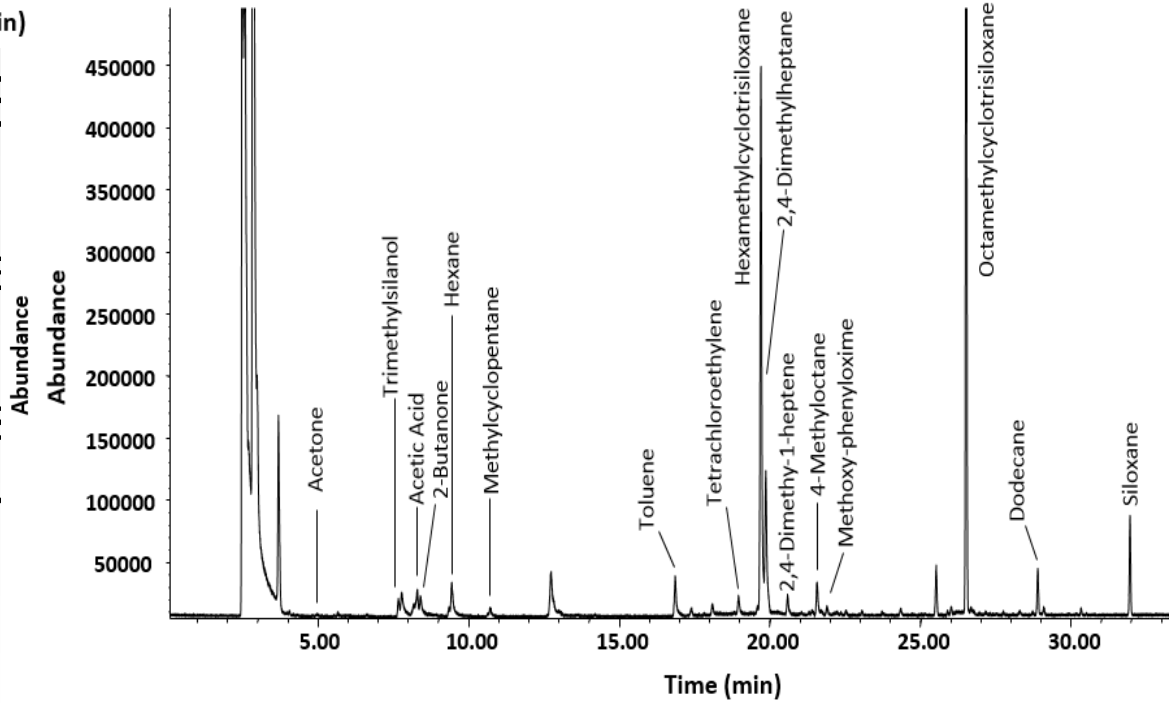
sed air)

Cs, alkanes/alkenes,

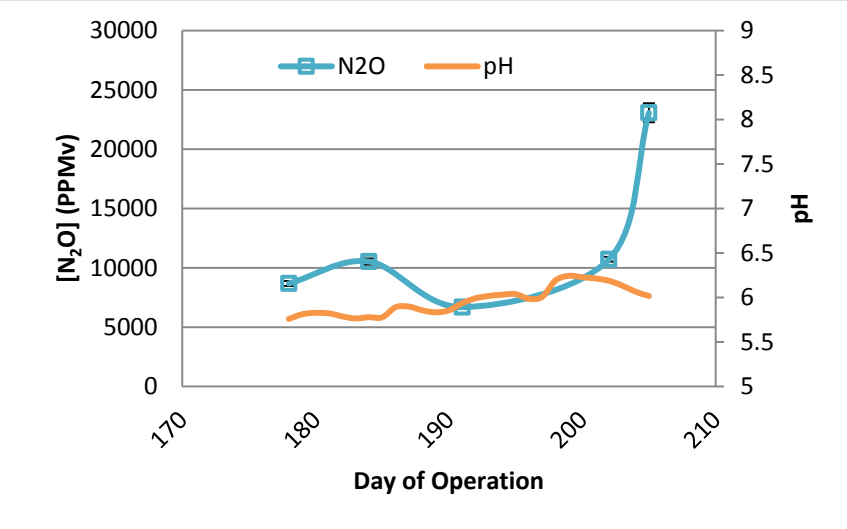
ed in compressor

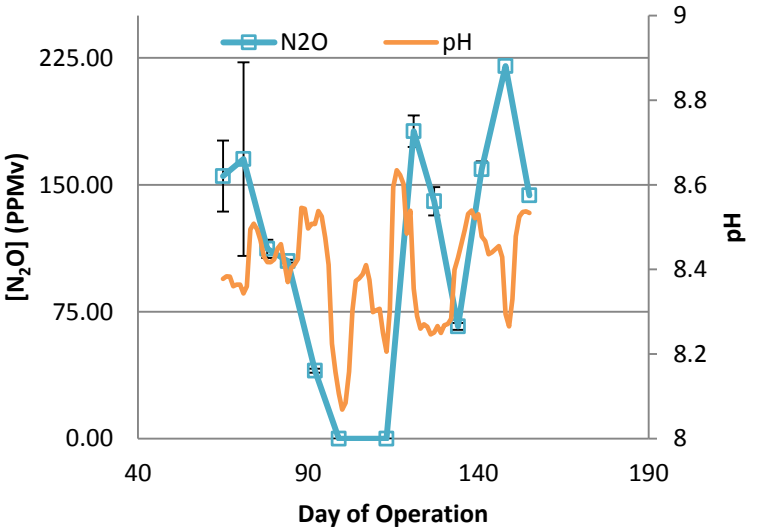


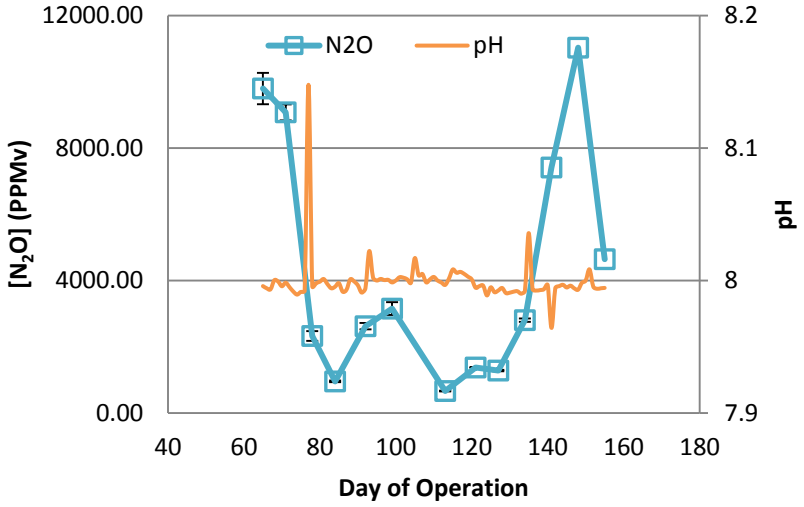

- JSC MABR's SPME
month period
  - Over time, profile
change significan
  - Based on findings
focused on for qu



- Process ga… $_2$, $N_2O$ and $CO_2$ were … ekly basis.
- $O_2$ and $N_2$ … oring



# Trace Contaminants

| Compound | Concentration (ppm) | | | |
|---|---|---|---|---|
| | MABR1 | MABR2 | MABR3 | MABR4 |
| $CO_2$ | 4,350-38,250 | 1,175-28,150 | 4,000-27,500 | 4,265-27,325 |
| $N_2O$ | 1,675-8,125 | 0-9,540 | 6,325-7,900 | 0-8,890 |
| $NO_2$ | 0 | 0 | N/A | 0 |
| EtOH | 0.003-0.013 | 0 | 0-0.054 | BDL |
| MeOH | BDL | BDL | BDL | BDL |
| Acetone | 0-0.08 | 0-0.06 | 0.007-0.08 | 0-0.06 |
| MEK | BQL | BQL | BQL | BQL |
| IPA | BQL | BQL | BQL | BQL |

- Siloxane trends show possible initial hardware off-gassing

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# Implications for Environmental Controls using ISS Technologies

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# Trace Contaminants

- Trace contaminants detected and quantified to date as significant: EtOH and Acetone
  - Estimated Added Daily Load per Bioreactor:
    - EtOH: 4-18 µg
    - Acetone: 12-137 µg
  - Average ISS Concentrations
    - EtOH: ~4 mg/$m^3$
    - Acetone: ~0.32 mg/$m^3$

# Nitrogenous Compounds

- Nitrogenous process gases: $N_2$, NO, $NO_2$, $N_2O$
  - $N_2$ generated difficult to determine due to use of air as feed gas and detector limits
  - NO readily oxidizes to NO2 in presence of oxygen and is not expected to accumulate
  - $NO_2$ in the effluent gas = supply gas levels
  - $N_2O$ levels may be of concern (up to 12.36 g/day)
    - No current SMAC value, but TWA for an 8-hour period = 25-50 ppm
    - Further evaluation of TCCS required to determine if this load can be handled
    - May be caused by suboptimal conditions for microbes and further reactor operation tweaks may be able to lower these levels.

# Carbon Dioxide

*$CO_2$ SMAC & ISS Controls*

- SMAC levels:
  - 1- & 24-hr: 13,000 ppm
  - 7-, 30-, 180-days: 7,000 ppm
- ISS Controls:
  - CDRA: removes $CO_2$ for up to 7 crew (up to 0.22 kg/hr)
  - Vozdukh: removes $CO_2$ for up to 5 crew (up to 0.22 kg/hr)

*Reactor Effluent*

- Range of 1.5 to 50 g $CO_2$ per reactor per day
- Processing of wastewater for crew of 4 required 2 reactors
  - Assuming highest levels of CO2, this adds 0.1 crew member for 2 reactors in operation.
- Large flux in CO2 output due to changes in microbial environment/operation parameters
  - Alterations may be able to level out or lower concentrations.

# Siloxanes and Sulfurous Compounds

## *Siloxanes*

- Siloxanes were present in both supply gas and effluent gas
- Trends demonstrated possible initial off-gassing of siloxane derivatives from reactor hardware that decreases over time.
- Accurate determination of off-gassing from silastic tubing and other hardware materials is warranted
  - May have unneccesary release of siloxanes causing further DMSD issues in water supply.
  - May require initial off-gassing period of reactors before put into use.

## *Sulfurous Compounds*

- During testing to date, effluent gases have not been examined for sulfur-containing compounds.
- If anoxic zones are present in the reactor, release is possible
- During subscale reactor biofilm harvests at KSC, there have been obvious scents common to sulfurous compounds.
- Requires further analysis
  - Can poison catalyst beds
  - Can be harmful to crew

# Conclusions

- Gaseous effluent analysis essential to bioreactor operation in closed environments
- Based on SPME results, many of the same compounds in the effluent were in the supply gas
- Trace contaminants detected, none are produced in appreciable amounts and are orders of magnitude lower than SMAC values
  - TCCS should be able to handle the small added load
- Nitrous oxide levels are of concern
- Carbon dioxide off-gassing from 2 reactors would add only 0.1 crew member to TCCS load
- Further investigation of siloxane off-gassing and detection of sulfurous compounds required

# Thank You!

Questions?